THE CLAIMS

What is Claimed is:

1. A method for sequentially separating components of milk, comprising the steps of:

   (a) providing a milk source;

   (b) effectuating a sufficient flow of milk from the milk source through one or more cross-flow filtration modules, using one or more fluid delivery means, wherein each fluid delivery means is connected to at least one cross-flow filtration module; and

   (c) sequentially capturing one or more filtration fractions generated by the cross-flow filtration modules.

2. A method according to claim 1, wherein each cross-flow filtration module comprises at least one permeate, at least one inlet, at least one outlet, and multiple fluid-flow sub-channels each extending between the inlet and outlet, that are of equal length to one another as measured between the inlet and the outlet.

3. A method according to claim 1, wherein the cross-flow filtration modules comprise filtration membranes selected from the group consisting of cellulose-based membranes, polymer-based membranes, and ceramic-based membranes.

4. A method according to claim 1, wherein the milk from the milk source is flown through a cream separator upstream of the cross-flow filtration modules to remove at least part of a fatty component of the milk.

5. A method according to claim 1, wherein the milk is pasteurized before being flowed to the cross-flow filtration modules.

6. A method according to claim 1, further comprising the step of controlling and monitoring temperature of the fluid within the cross-flow filtration modules.

7. A method according to claim 1, further comprising the step of recycling water generated by the cross-flow filtration modules.

8. A method according to claim 1, wherein the milk is flowed through a cross-flow filtration module to be separated into a casein-rich fraction and a casein-depleted fraction.

9. A method according to claim 8, wherein the casein-rich fraction of the milk is captured as retentate of the cross-flow filtration module, and wherein the casein-depleted fraction of the milk is captured as permeate of the cross-flow filtration module.

10. A method according to claim 8, wherein the cross-flow filtration module comprises a cellulose-based membrane selected from the group consisting of cellulose membranes, cellulose acetate membranes, and regenerated cellulose membranes.

11. A method according to claim 8, wherein the cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 3000KD.

12. A method according to claim 8, wherein the cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 1000KD.

13. A method according to claim 8, wherein the cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 500KD.

14. A method according to claim 8, wherein the cross-flow filtration module comprises a regenerated cellulose membrane having an average pore size of about 100KD.

15. A method according to claim 8, further comprising the step of concentrating and/or diafiltering the casein-rich fraction.

16. A method according to claim 8, further comprising the step of concentrating and/or diafiltering the casein-depleted fraction.

17. A method according to claim 8, wherein the casein-rich fraction is used to manufacture a diary product selected from the group consisting of: cheese, milk powder, and substrate for milk protein concentrate.

18. A method according to claim 8, wherein the casein-depleted fraction is used to manufacture a diary product selected from the group consisting of: whey protein isolates, whey protein subcomponents, and whey protein concentrates.

19. A method according to claim 8, further comprising the steps of:

adding fatty component of milk to the casein-rich fraction; and

drying said casein-rich fraction to form milk powder enriched with the fatty component of milk.

20. A method according to claim 1, comprising the steps of:

optionally flowing the milk from the milk source through a first cross-flow filtration module to remove at least a portion of bacteria contained therein;

flowing the milk, optionally filtered in the first cross-flow filtration module, through a second cross-flow filtration module to separate the milk into a casein-rich fraction and a casein-depleted fraction;

capturing the casein-rich fraction;

flowing the casein-depleted fraction of the milk through a third cross-flow filtration module to form a fraction that is enriched with albumin and immunoglobulins and a fraction that is depleted of albumin and immunoglobulins;

capturing the fraction that is enriched with albumin and immunoglobulins;

flowing the fraction that is depleted of albumin and immunoglobulins of the milk through a fourth cross-flow filtration module to form a β-lactoglobulin-rich fraction and a β-lactoglobulin-depleted fraction;

capturing the β-lactoglobulin-rich fraction;

flowing the β-lactoglobulin-depleted fraction of the milk through a fifth cross-flow filtration module to form a α-lactalbumin-rich fraction and a α-lactalbumin-depleted fraction;

capturing the α-lactalbumin-rich fraction;

flowing the α-lactalbumin-depleted fraction of the milk through a sixth cross-flow filtration module to form a complex carbohydrates rich fraction and a complex carbohydrates depleted fraction;

capturing the complex carbohydrates rich fraction;

flowing the complex carbohydrates depleted fraction through a seventh cross-flow filtration module to form a lactose-rich fraction and a lactose-depleted fraction;

capturing the lactose-rich fraction; and

discharging and/or recyclying the lactose-depleted fraction of milk.

21. A method according to claim 20, further comprising the step of pasteurizing the milk source and/or any fraction of the milk components generated therein.

22. A method according to claim 20, wherein the cross-flow filtration modules comprise filtration membranes selected from the group consisting of cellulose-based membranes, polymer-based membranes, and ceramic-based membranes.

23. A method according to claim 20, wherein the second cross-flow filtration module comprises a cellulose-based membrane selected from the group consisting of cellulose membranes, cellulose acetate membranes, and regenerated cellulose membranes.

24. A method according to claim 20, wherein the second cross-flow filtration module comprises a membrane having average pore size in the range from about 100KD to about 3000KD.

25. A method according to claim 20, wherein the second cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 1000KD, selected from the group consisting of cellulose-based membranes selected from the group consisting of cellulose membranes, cellulose acetate membranes, and regenerated cellulose membranes.

26. A method according to claim 20, wherein the second cross-flow filtration module comprises a polymeric membrane having an average pore size in a range of between 800KD and 2500KD and/or a measured bubble point between 65 and 120 PSIG.

27. A method according to claim 20, wherein the second cross-flow filtration module comprises a regenerated cellulose membrane having an average pore size of about 100KD.

28. A method according to claim 20, further comprising the step of separating and purifying albumin and immunoglobulins from the fraction that is enriched with albumin and immunoglobulins, using a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

29. A method according to claim 20, further comprising the step of separating and purifying β-lactoglobulin from the β-lactoglobulin-rich fraction of the milk, using a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

30. A method according to claim 20, further comprising the step of separating and purifying α-lactalbumin from the α-lactalbumin-rich fraction of the milk, using a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

31. A method according to claim 30, further comprising the step of adding the separated and purified α-lactalbumin into the casein-depleted fraction of the milk generated by the second cross-flow filtration module to form an α-lactalbumin-enriched soluble milk protein concentrate.

32. A method according to claim 31, further comprising the step of drying the α-lactalbumin-enriched soluble milk protein concentrate to form a powder product.

33. A method according to claim 20, further comprising the step of separating and purifying complex carbohydrates from the complex carbohydrates-rich fraction of the milk, using a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

34. A method according to 33, further comprising the step of fractioning the complex carbohydrates into one or more subcomponents using one or more cross-flow filtration modules.

35. A method according to claim 20, further comprising the step of subjecting the lactose-rich fraction of the milk to a bacterial process and/or an enzymatic process.

36. A method according to claim 20, further comprising the step of fermenting the lactose-rich fraction of the milk to produce at least one product selected from the group consisting of lactobacillus, lactic acid, and Vitamin B-12.

37. A method according to claim 20, further comprising the step of crystallizing the lactose-rich fraction of the milk to produce at least one product selected from the group consisting of lactobacillus, lactic acid, and Vitamin B-12.

38. A method according to claim 20, further comprising the step of combining the casein-rich fraction from the second cross-flow filtration module with the α-lactalbumin-rich fraction from the fifth cross-flow filtration module to form an α-lactalbumin-enriched substrate for cheese manufacturing.

39. A method according to claim 20, further comprising the step of drying at least one of the captured fractions of milk by a method selected from the group consisting of lyophilization, spray-drying, freeze-drying, crystallization, and evaporation.

40. A method according to claim 20, wherein each cross-flow filtration module is connected to at least one fluid delivery means for flowing the milk or a fraction of the milk therethrough.

41. A method according to claim 20, wherein temperature of each cross-flow filtration module is controlled and monitored by temperature controlling/monitoring means.

42. A method according to claim 1, wherein sialyllactose is isolated from the milk, said method comprising the steps of:

optionally flowing the milk from the milk source through a first cross-flow filtration module to filter out at least a portion of bacteria contained therein;

flowing the milk, optionally filtered in the first cross-flow filtration module, through a second cross-flow filtration module to separate the milk into a casein-rich fraction and a casein-depleted fraction;

capturing the casein-rich fraction;

flowing the casein-depleted fraction of the milk through a third cross-flow filtration module to form a fraction that is enriched with milk proteins selected from the group

consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin, and a fraction that is depleted of said milk proteins;

capturing the fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin;

flowing the fraction that is depleted of said milk proteins through a fourth cross-flow filtration module to form a sialyllactose-enriched fraction and a sialyllactose-depleted fraction;

capturing the sialyllactose-enriched fraction; and

discharging the sialyllactose-depleted fraction.

43. A method according to claim 1, wherein the milk source supplies casein-depleted whey, and wherein sialyllactose is separated from said casein-depleted whey, comprising the steps of:

optionally flowing the casein-depleted whey from the milk source through a first cross-flow filtration module to filter out at least a portion of bacteria contained therein;

flowing the casein-depleted whey, optionally filtered in the first cross-flow filtration module, through a second cross-flow filtration module to form a fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin, and a fraction that is depleted of said milk proteins;

capturing the fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin;

flowing the fraction that is depleted of said milk proteins through a third cross-flow filtration module to form a sialyllactose-enriched fraction and a sialyllactose-depleted fraction;

capturing the sialyllactose-enriched fraction; and

discharging the sialyllactose-depleted fraction.

44. A method according to claim 1, wherein immunoglobulins are isolated and purified from the milk, said method comprising the steps of:

optionally flowing the milk from the milk source through a first cross-flow filtration module to filter out at least a portion of bacteria contained therein;

flowing the milk, optionally filtered in the first cross-flow filtration module, through a second cross-flow filtration module to separate the milk into a casein-rich fraction and a casein-depleted fraction;

capturing the casein-rich fraction;

flowing the casein-depleted fraction of the milk through a third cross-flow filtration module to form an immunoglobulin-rich fraction and an immunoglobulin-depleted fraction; and

capturing both the immunoglobulin-rich fraction and the immunoglobulin-depleted fraction.

45. A method according to claim 44 further comprising the additional step of concentrating and/or diafiltering the immunoglobulin-rich fraction.

46. A method according to any one of claims 44 and 45 further comprising the additional step of purifying immunoglobulins from the immunoglobulin-rich fraction by a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

47. A method according to any one of claims 44, 45 and 46 further comprising the additional step of concentrating and/or diafiltering the immunoglobulin depleted fraction for further uses.

48. A method according to any one of claims 44, 45, 46 and 47 wherein the immunoglobulins have therapeutic effects.

49. A method according to any one of claims 44, 45, 46 and 47 wherein the immunoglobulins are used to treat gastrointestinal track disorder.

50. A method according to any one of claims 44, 45, 46 and 47 wherein the immunoglobulins are used to treat a mammal of the same species as that of the milk source.

51. A method according to any one of claims 44, 45, 46 and 47 wherein the immunoglobulins are used to treat a mammal of a different species from that of the milk source.

52. A method according to claim 1, wherein the milk source supplies fluid containing mixtures of complex carbohydrates and lactose, and wherein complex carbohydrates are isolated and purified from said mixtures, said method comprising the steps of:

flowing the fluid mixtures from the milk source through a first cross-flow filtration module to separate said mixtures into a complex carbohydrates rich fraction and a complex carbohydrate depleted fraction;

capturing both the complex carbohydrates rich fraction and the complex carbohydrates depleted fraction;

concentrating and/or diafiltering the complex carbohydrates rich fraction to obtain complex carbohydrates;

crystalizing and/or drying the complex carbohydrates; and

concentrating and/or diafiltering the complex carbohydrates depleted fraction to obtain lactose; and

crystalizing and/or drying the lactose.

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53~~52~~. A method according to claim 1, wherein sialyllactose is isolated from the milk, said method comprising the steps of:

flowing the milk from the milk source through a first cross-flow filtration module to separate the milk into a casein-rich fraction and a casein-depleted fraction;

capturing the casein-rich fraction;

flowing the casein-depleted fraction of the milk through a second cross-flow filtration module to form a fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin, and a fraction that is depleted of said milk proteins;

capturing the fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin;

flowing the fraction that is depleted of said milk proteins through a third cross-flow filtration module to form a sialyllactose-enriched fraction and a sialyllactose-depleted fraction;

capturing the sialyllactose-enriched fraction; and

discharging the sialyllactose-depleted fraction.

54 52. A method according to claim 1, wherein the milk source directly supplies casein-depleted whey, and wherein sialyllactose is separated from said casein-depleted whey, comprising the steps of:

flowing the casein-depleted whey from the milk source through a first cross-flow filtration module to form a fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin, and a fraction that is depleted of said milk proteins;

capturing the fraction that is enriched with milk proteins selected from the group consisting of albumin, immunoglobulins, β-lactoglobulin, and α-lactalbumin;

flowing the fraction that is depleted of said milk proteins through a second cross-flow filtration module to form a sialyllactose-enriched fraction and a sialyllactose-depleted fraction;

capturing the sialyllactose-enriched fraction; and

discharging the sialyllactose-depleted fraction.

55 ~~53.~~ A method according to claim 1, wherein immunoglobulins are isolated and purified from the milk, said method comprising the steps of:

flowing the milk from the milk source through a first cross-flow filtration module to separate the milk into a casein-rich fraction and a casein-depleted fraction;

capturing the casein-rich fraction;

flowing the casein-depleted fraction of the milk through a second cross-flow filtration module to form an immunoglobulin-rich fraction and an immunoglobulin-depleted fraction;

capturing both the immunoglobulin-rich fraction and the immunoglobulin-depleted fraction;

56 ~~54.~~ A method according to claim 53 further comprising the additional step of concentrating and/or diafiltering the immunoglobulin-rich fraction.

57 ~~55.~~ A method according to any one of claims 53 and 54 further comprising the additional step of purifying immunoglobulins from the immunoglobulin-rich fraction by a method selected from the group consisting of chromatography, cross-flow filtration, cross-flow chromatography, and diafiltration.

58 ~~56.~~ A method according to claim 53 further comprising the additional step of concentrating and/or diafiltering the immunoglobulin depleted fraction for further uses.

59 ~~57.~~ An apparatus for sequentially separating components of milk, comprising:

(a) a milk source;

(b) one or more cross-flow filtration modules communicatively connected to said milk source, for generating one or more filtration fractions;

(c) one or more fluid delivery means connected to each of said cross-flow filtration modules to effectuate flow of milk through said cross-flow filtration modules for separation of milk components; and

(d) one or more means downstream of each of said cross-flow filtration modules for sequentially capturing one or more filtration fractions generated by the cross-flow filtration modules.

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~~58.~~ An apparatus according to claim 50, wherein each cross-flow filtration module comprises at least one permeate, at least one inlet, at least one outlet, and multiple fluid-flow sub-channels that are of equal length between the inlet and the outlet.

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~~59.~~ An apparatus according to claim 57, wherein the one or more cross-flow filtration modules comprise a filtration membrane selected from the group consisting of cellulose-based membranes, polymer-based membranes, and ceramic-based membranes.

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~~60.~~ An apparatus according to claim 57, further comprising a cream separator upstream of said cross-flow filtration modules for removing at least a portion of fatty component from the milk.

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~~61.~~ An apparatus according to claim 57, further comprising a pasteurizer upstream and/or downstream of said one or more cross-flow filtration modules for pasteurizing the milk.

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~~62.~~ An apparatus according to claim 57, further comprising temperature controlling/monitoring means for controlling and monitoring temperature of said milk and/or filtration fractions generated by the one or more cross-flow filtration modules.

65 ~~63.~~ An apparatus according to claim 57, comprising a cross-flow filtration module for separating the milk from the milk source into a casein-rich fraction and a casein-depleted fraction.

66 ~~64.~~ An apparatus according to claim 63, wherein the cross-flow filtration module comprises membranes selected from the group consisting of cellulose-based membranes, polymer-based membranes, and ceramic-based membranes.

67 ~~65.~~ An apparatus according to claim 63, wherein the cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 3000KD.

68 ~~66.~~ An apparatus according to claim 63, wherein the cross-flow filtration module comprises a membrane having an average pore size in a range of from about 100KD to about 1000KD, selected from the group consisting of cellulose-based membranes selected from the group consisting of cellulose membranes, cellulose acetate membranes, and regenerated cellulose membranes.

69 ~~67.~~ An apparatus according to claim 63, wherein the cross-flow filtration module comprises a polymeric membrane having an average pore size between 800KD and 2500KD and/or a measured bubble point between 65 and 120 PSIG.

70 ~~68.~~ A method according to claim 63, wherein the cross-flow filtration module comprises a regenerated cellulose membrane having an average pore size of about 100KD

~~69~~ 69. An apparatus according to claim 57, comprising:

an optional first cross-flow filtration module downstream of the milk source and communicatively connected thereto for filtering out all or at least a portion of bacteria contained in the milk;

a second cross-flow filtration module, downstream of the first cross-flow filtration module if provided and communicatively connected thereto, or if not provided, then communicatively connected directly to the milk source, which separates the milk into a casein-rich fraction and a casein-depleted fraction;

means connected to said second cross-flow filtration module for capturing the casein-rich fraction;

a third cross-flow filtration module downstream of the second cross-flow filtration module and communicatively connected thereto, which receives the casein-depleted fraction and further separates it into a fraction that is enriched with albumin and immunoglobulins and a fraction that is depleted of albumin and immunoglobulins;

means connected to said third cross-flow filtration module for capturing the fraction that is enriched with albumin and immunoglobulins;

a fourth cross-flow filtration module downstream of the third cross-flow filtration module and communicatively connected thereto, which receives the fraction that is depleted of albumin and immunoglobulins and further separates it into a β-lactoglobulin-rich fraction and a β-lactoglobulin-depleted fraction;

means connected to said fourth cross-flow filtration module for capturing the β-lactoglobulin-rich fraction;

a fifth cross-flow filtration module downstream of the fourth cross-flow filtration module and communicatively connected thereto, which receives the β-lactoglobulin-depleted fraction and further separates it into a α-lactalbumin-rich fraction and a α-lactalbumin-depleted fraction;

means connected to said fifth cross-flow filtration module for capturing the α-lactalbumin-rich fraction;

a sixth cross-flow filtration module downstream of the fifth cross-flow filtration module and communicatively connected thereto, which receives the α-lactalbumin-depleted fraction and further separates it into a complex carbohydrates rich fraction and a complex carbohydrates depleted fraction;

means connected to said sixth cross-flow filtration module for capturing the complex carbohydrates rich fraction;

a seventh cross-flow filtration module downstream of the sixth cross-flow filtration module and communicatively connected thereto, which receives the complex carbohydrates depleted fraction and further separates it into a lactose-rich fraction and a lactose-depleted fraction; and

means connected to said seventh cross-flow filtration module for capturing the lactose-rich fraction;

means for discharging and/or recycling the lactose-depleted fraction.

72 70. An apparatus according to claim 57, comprising:

a first cross-flow filtration module downstream of the milk source and communicatively connected thereto, which separates the milk into a casein-rich fraction and a casein-depleted fraction;

means connected to said first cross-flow filtration module for capturing the casein-rich fraction;

a second cross-flow filtration module downstream of the first cross-flow filtration module and communicatively connected thereto, which receives the casein-depleted fraction and further separates it into a fraction that is enriched with albumin and immunoglobulins and a fraction that is depleted of albumin and immunoglobulins;

means connected to said second cross-flow filtration module for capturing the fraction that is enriched with albumin and immunoglobulins;

a third cross-flow filtration module downstream of the second cross-flow filtration module and communicatively connected thereto, which receives the fraction that is depleted of albumin and immunoglobulins and further separates it into a β-lactoglobulin-rich fraction and a β-lactoglobulin-depleted fraction;

means connected to said third cross-flow filtration module for capturing the β-lactoglobulin-rich fraction;

a fourth cross-flow filtration module downstream of the third cross-flow filtration module and communicatively connected thereto, which receives the β-lactoglobulin-depleted fraction and further separates it into a α-lactalbumin-rich fraction and a α-lactalbumin-depleted fraction;

means connected to said fourth cross-flow filtration module for capturing the α-lactalbumin-rich fraction;

a fifth cross-flow filtration module downstream of the fourth cross-flow filtration module and communicatively connected thereto, which receives the α-lactalbumin-depleted fraction and further separates it into a complex carbohydrates rich fraction and a complex carbohydrates depleted fraction;

means connected to said fifth cross-flow filtration module for capturing the complex carbohydrates rich fraction;

a sixth cross-flow filtration module downstream of the fifth cross-flow filtration module and communicatively connected thereto, which receives the complex carbohydrates depleted fraction and further separates it into a lactose-rich fraction and a lactose-depleted fraction; and

means connected to said sixth cross-flow filtration module for capturing the lactose-rich fraction;

means for discharging and/or recycling the lactose-depleted fraction.

~~73~~ 71. An apparatus according to any one of claims 69 and 70, further comprising a pasteurizer upstream and/or downstream of any of the cross-flow filtration modules for pasteurizing the milk source or any one or more filtration fractions generated by the cross-flow filtration modules.

~~74~~ 72. An apparatus according to any one claims 69 and 70, comprising multiple fluid delivery means arranged in a manner that each cross-flow filtration module is connected to at least one fluid delivery means, said fluid delivery means function to effectuate a flow of the milk or a fraction of the milk through each cross-flow filtration module.

~~75~~ 73. An apparatus according to any one of claims 69 and 70, further comprising temperature controlling/monitoring means for controlling and monitoring temperature of said milk and/or filtration fractions generated by the cross-flow filtration modules.

~~76~~ 74. An apparatus according to any one of claims 69 and 70, further comprising a cream separator upstream of said cross-flow filtration modules for removing all or at least a portion of fatty component from the milk.

~~77~~ 75. A method of milk separation, comprising separating milk to recover at least one milk product therefrom, by cross-flow membrane filtration, wherein said method does not include any chromatography or precipitation steps.

76. The method of claim 75, wherein the milk product comprises a material selected from the group consisting of fats, lipids, insoluble casein, immunoglobulins, albumin, beta-lactoglobulin, alpha-lactalbumin, complex carbohydrates, siallyllactose, simple carbohydrates, lactose.

77. The method of claim 75, wherein the cross-flow membrane filtration is carried out in a cross-flow filtration module including a filter with geometrically regular subchannels geometrically corresponding to one another in a flow passage for said filtration, wherein operating conditions and/or said subchannels have been optimized with respect to shear rate and/or permeate diffusion.

78. A α-lactalbumin-enriched soluble milk protein concentrate.

79. A β-lactoglobulin and α-lactalbumin-enriched whey protein isolate.

80. A sialyllactose-enriched whey protein isolate.